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ABSTRACT

This study investigated patterns and effects of cognitive tools usage during engagement with an open-ended hypermedia learning environment. Seven technical institute students engaged in problem-solving tasks concerning anatomy and physiology. They used 16 cognitive tools embedded in a hypermedia system and their tool use patterns and corresponding learning processes were explored and analyzed. The findings suggest that four factors (general prior knowledge, task-related prior knowledge, task complexity, and tool familiarity) affected learner's selection and use of cognitive tools. Effects of learners, tasks, and learning environment interaction on tool use are also discussed. A conceptual framework for functional cognitive tool classifications and principles of design based on an information processing model and other cognitive learning theories such as cognitive flexibility theory, cognitive load theory, metacognition theory, and mental model theory are provided. Appendixes provide a sample screen image and explanation of tools from "The Human Body" and functional classification tools from that text. (Contains 1 table, 1 figure, and 15 references.) (Author/SLD)

Cognitive Tools for Open-Ended Learning Environments: Theoretical and Implementation Perspectives

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Abstract: This study investigated patterns and effects of cognitive tools usage during engagement with an open-ended hypermedia learning environment. Seven technical institute students engaged in problem-solving tasks concerning anatomy and physiology. They used sixteen cognitive tools embedded in a hypermedia system and their tool use patterns and corresponding cognitive learning processes were explored and analyzed. The findings suggested that four factors, general prior knowledge, task-related prior knowledge, task complexity, and tool familiarity, affected learner's selection and use of cognitive tools. Effects of learners, tasks and learning environment interaction on tool use are also discussed. A conceptual framework for functional cognitive tool classifications and principles of design based on an information processing model and other cognitive learning theories such as cognitive flexibility theory, cognitive load theory, metacognition theory and mental model theory are provided.

Hypermedia systems have facilitated the application of constructionism in computer-mediated learning (Allen & Hoffman, 1991; Spiro, Feltovich, Jacobson, & Coulson, 1991; Cognition and Technology Group at Vanderbilt University, 1992; and Duffy & Jonassen, 1992). Exploration of open-ended hypermedia learning environments is considered a powerful and appropriate learning activity for individual knowledge and skills construction.

Despite considerable interest and potential for constructivistic open-ended learning environments, learning with open hypermedia systems often result in learners' "disorientation" and "cognitive overload" (Marchionini, 1988; Oren, 1990; Rosselli, 1991). Although many hamper learning via hypermedia, perhaps the most common and serious factor is that learners are often ill-equipped cognitively, to explore vast information network and construct unique meaning accordingly.

A principal cause of "disorientation" and "cognitive overload," often cited in open-ended hypermedia learning environments, has been the quantity of simultaneous information which a learner needs to process. Open-ended hypermedia learning environments place primary responsibility on the learner for accessing, organizing, and analyzing information (Newmark, 1989; Jonassen & Grabinger, 1990). Therefore, a fundamental problem exists where the basic strategy of such systems places an unusual burden on the learner.

Although several studies have been conducted investigating the effects of cognitive tools with hypermedia-based learning, few studies have effectively linked tool usage with differentiated cognition. We lack a well-integrated psychological framework which establishes a link between various tools and the nature of cognition required of, or resulting from, their use.

Learning with open hypermedia systems may be more successful if appropriate cognitive tools are provided to support the cognitive processing capabilities of learners. By using cognitive tools, learners may be better able to apply their potential higher-order knowledge and thinking skills, make learning decisions strategically, and assess their learning progress. A greater understanding of the patterns and effects of cognitive tool use in hypermedia learning environments is needed to establish stronger empirical and theoretical foundations of design and use of such tools.

Conceptual Framework

Kozma (1987) advocated the use of the computer as an information processor to facilitate cognitive processing. If the goal of computer-based cognitive tools is to upgrade cognitive processing in "a person-machine system of partnership" (Salomon, Perkins, & Globerson, 1991), the information processing model shows promise for providing a basis for cognitive tools classifications.

Cognitive tools can be classified according to the modified information-processing model (Figure 1), with learners as both processors of information and constructors of knowledge. This model is a modified version of Mayer's (1992) cognitive model of knowledge construction.

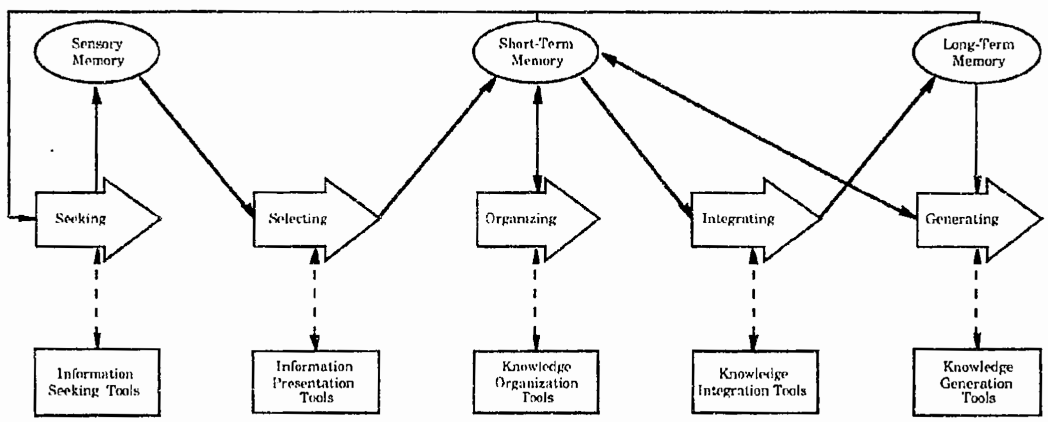


Figure 1. Overview of cognitive information processing model and the functional classification of cognitive tools (Iiyoshi & Hannafin, 1996).

In this model, there are five functional cognitive tool classifications: information seeking tools, information presentation tools, knowledge organization tools, knowledge integration tools, and knowledge generation tools. Each tool function supports a corresponding cognitive process phase. The significance of each tool classification, as well as the principles of design and use for each tool per the four cognitive theories, is developed. A summary of tool classifications, roles, and functions is shown in Table 1.

Table 1. Functional cognitive tool classifications, roles, and principles of design and use

Functional Tool Classifications	Roles of Tools	Principles of Design and Use
1. Information Seeking Tools	• Support learners as they attempt to identify and locate relevant information • Support learners to retrieve new and existing knowledge	• Provide multiple perspectives via varied information seeking strategies (Cognitive Flexibility Theory) • Support learners in monitoring their information seeking activities (Metacognitive Theory)
2. Information Presentation Tools	• Support learners as they attempt to present the information they encounter • Assist in clarifying the relationship among the information	• Provide multi-modal representations (Cognitive Flexibility Theory) • Reduce demands on working memory (Cognitive Load Theory)
3. Knowledge Organization Tools	• Support learners as they attempt to establish conceptual relationships in to-be-learned information • Help learners to interpret, connect, and organize the represented information meaningfully	• Avoid oversimplifications of complex conceptual schemata (Cognitive Flexibility Theory) • Help learners to simplify unnecessarily complex cognitive tasks (Cognitive Load Theory) • Facilitate self-regulated organization (Metacognition Theory)
4. Knowledge Integration Tools	• Support learners in connecting new with existing knowledge • Facilitate the processing of content at deeper levels in order to construct personally meaningful knowledge	• Facilitate the sophistication of conceptual understanding (Mental model theory) • Help learners to monitor knowledge construction process as well as their knowledge status (Metacognition Theory)
5. Knowledge Generation Tools	• Support the manipulation and generation of knowledge • Help learners to represent their newly generated knowledge flexibly and meaningfully	• Encourage multiple perspective and multi-modal knowledge generation (Cognitive Flexibility Theory) • Allow learners to select varied cognitive strategies (Metacognition Theory)

Purpose and Research Questions

The research investigated the use of cognitive tools in an open-ended hypermedia environment for learning anatomy and physiology. The purpose of this research was to investigate patterns and effects of cognitive tools usage during engagement with an open-ended hypermedia learning environment. These tools were designed to enhance learners cognitive processing capabilities to 1) seek information, 2) present information, 3) organize knowledge, 4) integrate knowledge, and 5) generate knowledge while integrating in the hypermedia system. An information-processing model (Figure 1) was used to classify the functional attributes of cognitive tools and to analyze associated cognitive processing.

The research addresses the following research questions related to the use of cognitive tools in an open-ended hypermedia learning environment:
1) Are tools used as initially intended?; 2) Do patterns of cognitive tool utilization exist?; and 3) How do individuals use multiple cognitive tools to accomplish tasks?

Methods and Procedures

The participants were seven technical institute students, ranging in age from nineteen to fifty years, enrolled in either the Nursing program or the Physical Therapist Assistant program at the Athens Area Technical Institute in Athens, Georgia. Participants familiarity with the subject matter was determined by a pre-study assessment of general anatomical concepts. Diverse familiarity with the subject matter was ensured, representing very limited, average, and extensive prior knowledge.

The open-ended hypermedia learning environment used for the study was *The Human Body*, a CD-ROM interactive multimedia system. A sample screen image of the system is shown in Figure 2. *The Human Body* combines computer graphics, digital video, sound, and text in an open-ended hypermedia learning environment to support constructivistic learning (Iiyoshi & Kikue, 1995; 1996). In the actual study, the hypermedia database in *The Human Body*, da Vinci's Book, which contains over one thousand individual screens was used. A total of sixteen cognitive tools embedded in da Vinci's Book were used. A sample screen image and brief explanations of these tools are shown in Appendix A. The functional classifications of these tools, based on information processing theory, are shown in Appendix B.

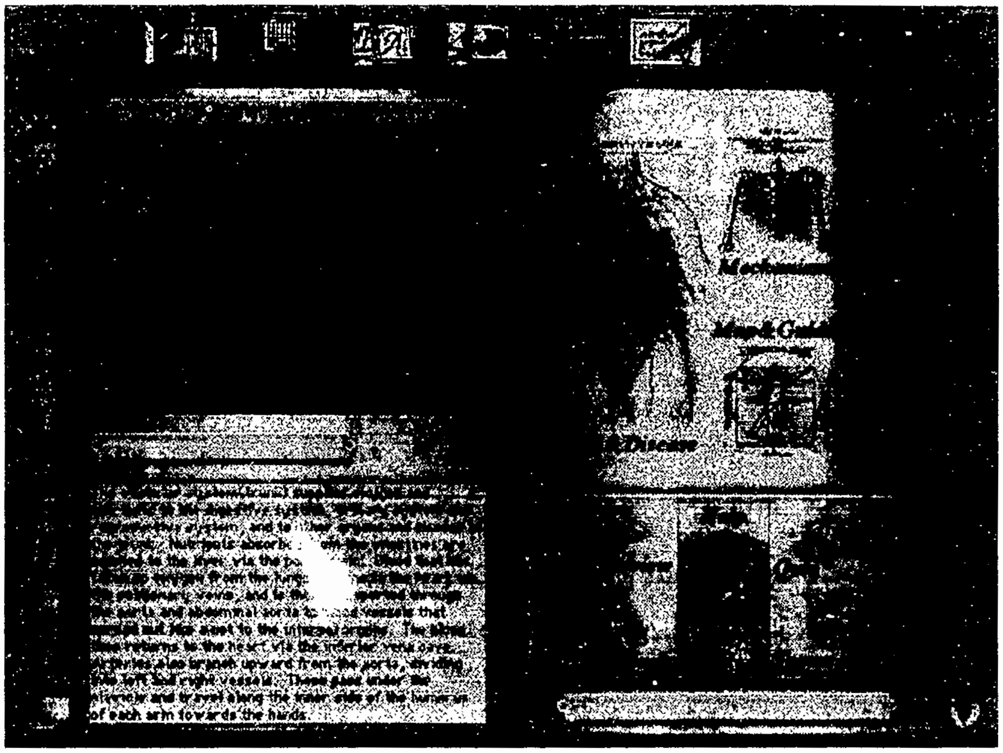


Figure 2. A sample screen image of *The Human Body*

Research procedures included nine primary activities: 1) developmental test of research methods; 2) pretest; 3) orientation of learners to the da Vinci's Book system; 4) think-aloud training exercise; 5) learner use of the da Vinci's Book system with the cognitive tools; 6) oral presentation by the learner; 7) retrospection; 8) questionnaires; and 9) summative interview.

There were five learning sessions. Each session was held on a different day. In each session, each individual was given a pool of learning tasks. The difficulty and complexity of these learning tasks increased as learning progressed. There were five groups of tasks which were vary according to complexity. Group 1 included six directed tasks on initial search and identification such as "list the three major components of the blood, and describe their general function." They provided varied activities to familiarize participants to the tools. Group 2 included four structured problem solving-tasks such as "describe how optic cells receive lights and convert them to electrical signals." They identified requisite concepts and terminology of the tasks to the participants. Group 3 provided five loosely structured problem-solving tasks such as "how body temperature is regulated?" in which elements and structures are ambiguous and the participants must generate strategies and sub-problems. Group 4 focused on learning about the endocrine system. The participants were expected to maximize their cognitive capabilities through use of the tools to learn as much as they could about the given subject. Group 5 was learning about a topic which was selected by each learner. The tasks such as "identify lifestyle changes to keep the heart healthy" were set by the learners.

Three instruments were used in the study: Multiple Choice Pretest; Perceptions of Tool Use Questionnaire; and Task-Based Learning Process Questionnaire. In addition, five data collection/analysis techniques were used: Action Protocols; Think-Aloud Protocols; Retrospection; Summative Interview; and Product Analysis.

Results and Implications

The functionality of the tools and the types of cognitive processing they supported were cross-indexed to examine whether actual tool use related to the cognitive process(s) it was initially intended to support. The analyzed data indicated that most tools (13 out of 16) were used as intended though the frequency of use varied widely. The learners reported that their perceptions of usefulness of these tools were mostly positive.

Four factors which affect learner's selection and use of tools emerged from an analysis of action protocols, think-aloud protocols, retrospection protocols, questionnaire on tool use, and questionnaire on task based learning processes: 1) *general prior knowledge*, 2) *task-related prior knowledge*, 3) *task complexity*, and 4) *tool familiarity*.

General prior knowledge influenced the way learners used the tools for information seeking and information presentation. The learners with higher general prior knowledge preferred to use tools, such as the *Structure Map* and the *General Index*, which the learners could use more effectively with their higher domain knowledge. It was also found that the learner who had medium general prior knowledge varied in tool use more than those who had high and low general prior knowledge.

Compared to general prior knowledge, task-related prior knowledge was more influential on the learners' tool use overall. In addition to information seeking tools and information presentation tools which general prior knowledge primarily affected, task-related prior knowledge also affected further cognitive processes: organization, integration, and generation of knowledge.

Task complexity affected the way learners used the tools to search for information, to organize knowledge, to integrate knowledge, and to generate knowledge. While the learners were working on simpler tasks such as merely locating information, they tended to use general tools such as the *General Index* and the *Hypertext*. However, while working with more complex tasks, they tended to use tools to help them organize their knowledge systematically such as the *Structure Map*. The learners also preferred to use the *Presentation Maker* to integrate and generate their knowledge with high complexity tasks.

Familiarity with the tools often affected selection and use of appropriate tools for specific cognitive learning processes. In the early learning sessions, lack of familiarity with the tools seemed to be one of the most significant obstacles to successful learning (e.g., "My unfamiliarity with the system is really the difficulty.") However, the more time they spent on using tools, the more accurate and efficient their tool use became (e.g., "It's getting used to, figuring out how to get real specific information takes me a little while to figure out which tool to use.") Eventually, all the learners became aware of how each tool helps them differently for different kinds of cognitive tasks but still tool use frequency varied widely.

The findings also suggested that there are primarily three common phases of multiple tool use strategies; 1) *identification*, 2) *exploration*, and 3) *optimization*. The progression of multiple tool use is facilitated by learners' tool familiarity, knowledge level, and task complexity.

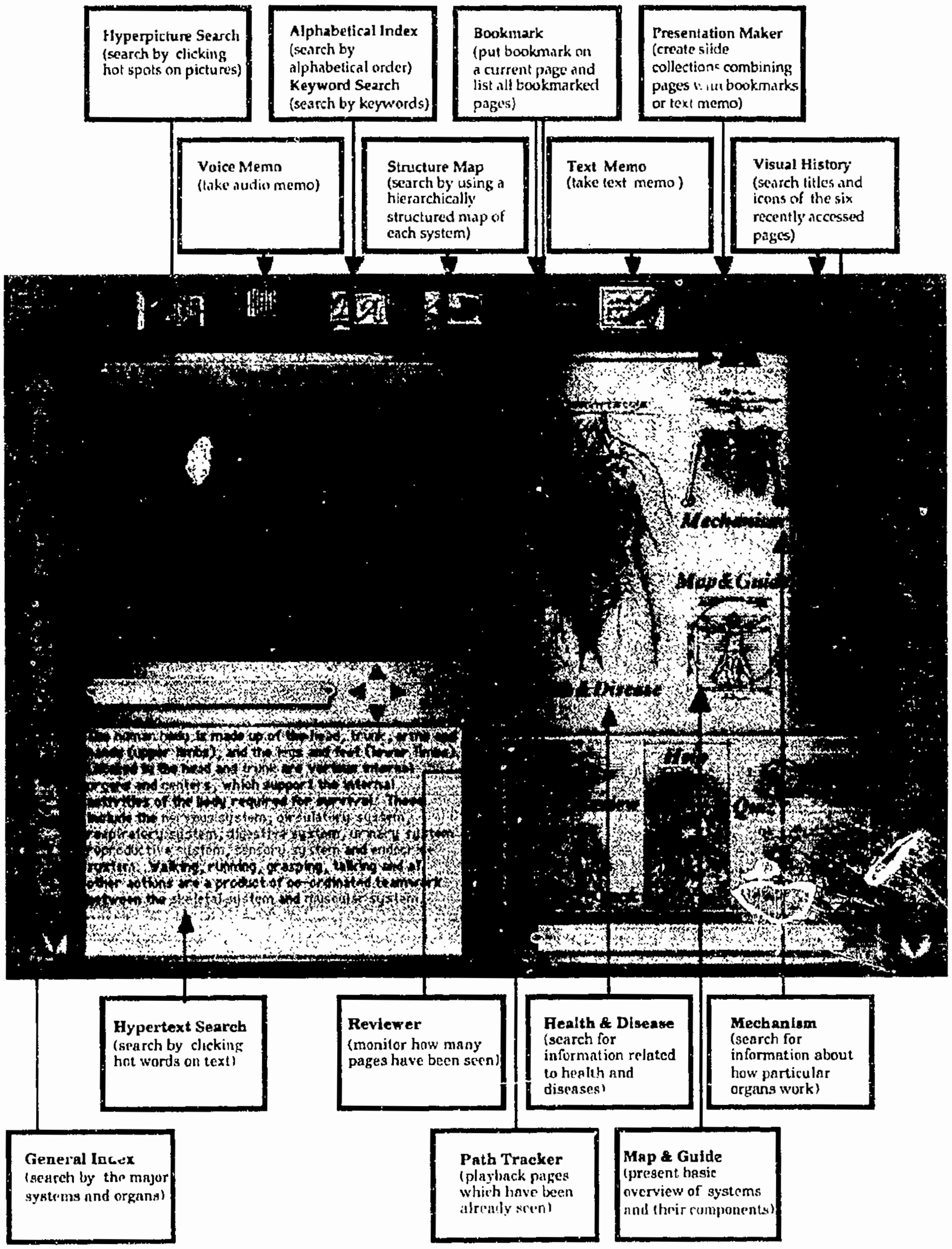
In the first phase, *identification*, the learners attempted to discover how each tool can help them in accomplishing basic tasks such as locating information they needed, or going back to previously seen information. In this stage, single use of each tool was not often driven by coherent multiple tool use strategies. Rather, each single tool was used independently, step by step, and not necessarily a tool most suitable for the task. The learners gradually became aware of which tool does what as they learned with tools.

During the second phase, *exploration*, trial and error in tool use shaped the learners mental model for using multiple tools in more efficient and useful way. In comparison with other tool use, the learners usually started recognizing which tool works better in order to accomplish a specific task. They also started using few tools together simultaneously to accomplish higher-order tasks. For example, when the learners couldn't remember a specific term they wanted to look up (e.g., schizophrenia), going through the list of *Alphabetical Index* one by one would be one way, but instead, if they knew some terms (e.g., mental illness) that are related to the term, they could find the term by using the *Keyword Search* and the *Hypertext*. In other words, the learners started seeing "chunks" of subordinate tasks and combining a useful tool set for a particular chunk. The learners tended to use more kinds of tools more often than they do in other stages.

In the last phase, *optimization*, the learners attempted to optimize the way they use multiple tools. In this stage, the learners often started working on tasks with some execution plans for how to use multiple tools to accomplish overall tasks (e.g., "The first night I wasn't quite certain how all these things would help me. But now I think it depends on the question... You have to sit and think how to answer each question which one [tool] would benefit me the most"). They broke tasks into manageable units and select a optimal set of tools they can use for each unit (e.g., "Actually, the combination of the different functions of the tools rather than the individual tool itself was really helpful. Because sometime you can learn as much by eliminating things as you can by accidentally finding stuff"). The kinds of tools used as well as the frequency of tool use tend to be diminished compared to the *exploration* phase.

The psychological framework and findings of this study would provide a practical guideline for design, use, and evaluation of cognitive tools for open-end learning environments. However, this study focused on tools for individual learners rather than a community of learners. As the interests in on-line learning systems such as the World Wide Web grow, the needs of "social" cognitive tools which support students' collaborative learning become more significant. Furthermore, unlimited and often unstructured resources in these "truly open" learning environments would place more cognitive burdens on the learners. Thus, research efforts to investigate more effective design and use of cognitive tools must be continued and expanded.

Appendix A. A sample screen image and brief explanations of tools in *The Human Body*



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Appendix B. Functional classifications of cognitive tools in *The Human Body*

	Information Seeking Tools	Information Presentation Tools	Knowledge Organization Tools	Knowledge Integration Tools	Knowledge Generation Tools
Alphabetical Index	√				
Bookmark	√	√	√		
General Index	√				
Health & Diseases	√				
Hyperpicture	√		√		
Hypertext	√		√		
Keyword Search	√				
Map & Guide	√	√	√		
Mechanism	√	√	√		
Path Tracker	√	√			
Presentation Maker		√	√	√	√
Reviewer	√	√			
Structure Map	√	√	√		
Text Memo	√	√	√	√	√
Visual History	√	√			
Voice Memo	√	√	√	√	√

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